Transportation Technology for the 21st Century: Fuel Cells

NREL/China Study Tour

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Outline of Presentation

- Fuel Cells
  - Basic Principles, Technology Overview
- Industry Activity
  - Development of Fuel Cell Vehicles
- Sustainable Transportation
  - Strategic Implications of Fuel Cells
  - Fuel Choice

Fuel Cells in Transportation

Fuel Cells

- Basic Principles
- Overview of Fuel Cell Technologies
  - Status
  - Applications
  - Federal Agency Activities

Electrochemical Engine

- Very high energy conversion efficiencies
- Fuel flexible
- Zero or very low emissions
- Mobile and stationary applications
- Modular

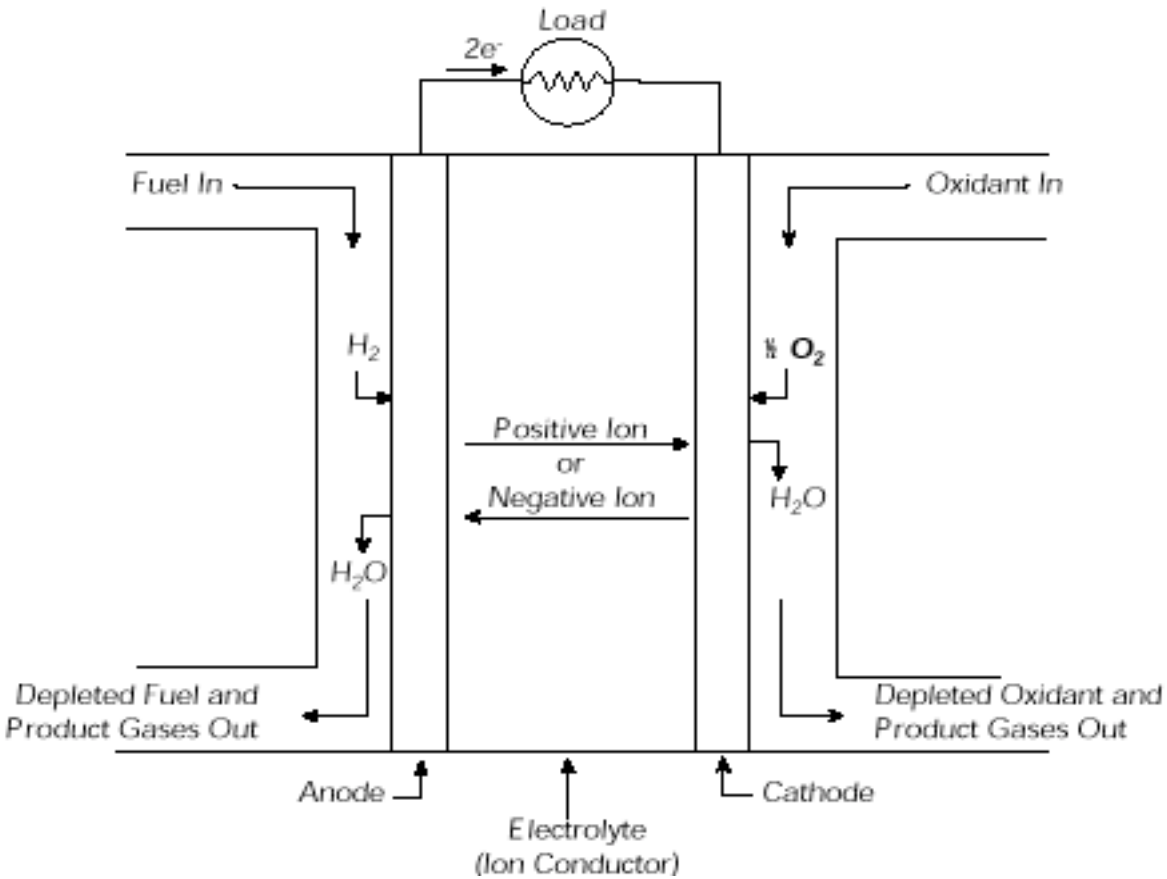
Fuel Cell Technologies

	PEFC	PAFC	MCFC	SOFC
Electrolyte	Ion Exchange Membrane	Immobilized Liquid Phosphoric Acid	Immobilized Liquid Molten Carbonate	Ceramic
Operating Temperature	80°C	205°C	650°C	800-1000°C now, 600-1000°C in 10 to 15 years
Charge Carrier	H^+	H^+	$CO3^=$	$O^=$
External Reformer for CH_4 (below)	Yes	Yes	No	No
Prime Cell Components	Carbon-based	Graphite-based	Stainless Steel	Ceramic
Catalyst	Platinum	Platinum	Nickel	Perovskites
Product Water Management	Evaporative	Evaporative	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Independent Cooling Medium	Process Gas + Independent Cooling Medium	Internal Reforming + Process Gas	Internal Reforming + Process Gas

Advantages and Disadvantages

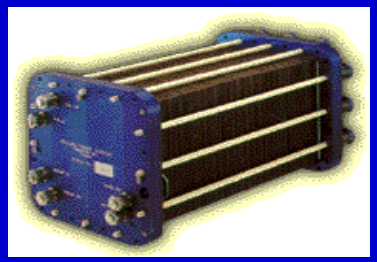
PEFC	AFC	PAFC	MCFC	SOFC
Solid Electrolyte Low Temperature Rapid Response High Current Density Little Gas X-over	First Modern FC Low Temperature Space Applications Excellent O_2 kinetics Catalyst Flexibility	Acid Electrolyte (CO_2 tolerant) Medium Temperature No Membrane Atmospheric Pressure Commercial Use Co-gen Possible	Higher Temperature Cheaper Catalysts Internal Reforming Use CO as Fuel Co-gen CO_2 tolerant (biogas) Co-gen	Solid Electrolyte Highest Temperature Ceramic Construction Fast Kinetics Internal Reforming Use CO as Fuel Fabrication Co-gen
Expensive Catalysts CO Poisoning Expensive Materials Machining Thermal Management Water Management Durability	Pure Hydrogen Pure Oxygen Limited Development for Terrestrial Uses	Expensive Catalysts External Reforming CO Poisoning Water-shift	Corrosive CO2 Required Low S Tolerance Mechanical Stability	Thermal Expansion Sealing Material Selection Fabrication Electrical Resistivity

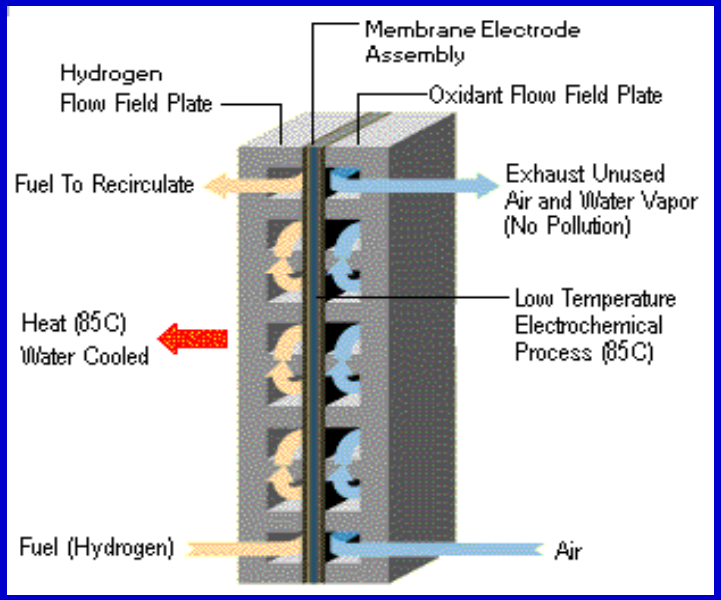
Schematic of Fuel Cell

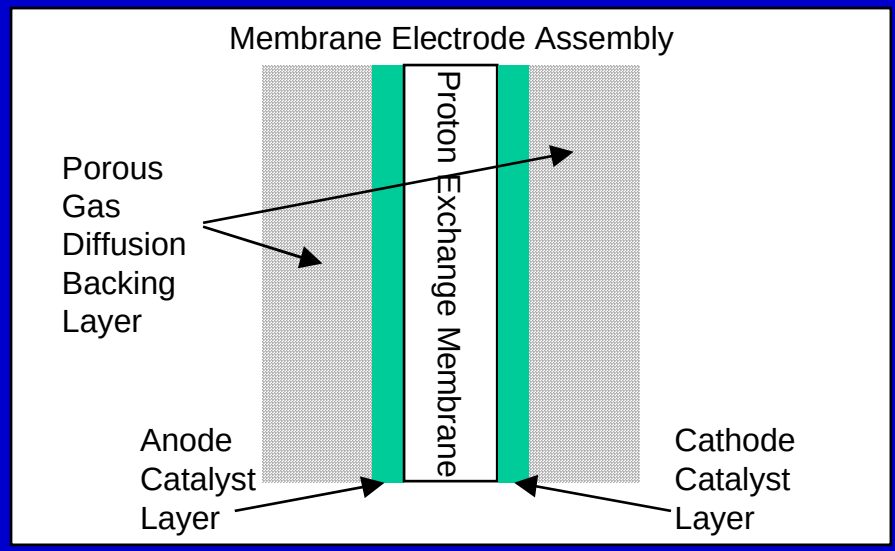


Introduction: Stacks and Cells

Fuel Cell Stacks are composed of a number of fuel cells electrically connected in series.







Federal Agencies

- DOE/EE: $32M PEMFC, $25M H_2R&D
- DOE/FE: $50M Stationary Systems
- DOT/FTA: Hydrogen Bus Demos
- NASA: Advanced Shuttle FC, RegenFC
- DOD/ARPA: Portable Systems, DMFC

Industry Efforts

- Daimler-Chrysler-Ford-Ballard
- Toyota
- GM
- Honda
- ZEVCo
- Ballard-GPU
- PlugPower (Detroit Edison-GE)

Industry Efforts

Ford P2000 Fuel Cell Car

Daimler-Chrysler
Jeep Commander

Industry Efforts

GM Precept Fuel Cell Car

Industry Efforts

Daimler-Benz NECAR III

Daimler-Benz NEBUS

Industry Efforts

Daimler-Chrysler necar 4

Industry Efforts

BMW Series 700 Hydrogen Vehicle

Industry Efforts

Toyota

Prius HEV

RAV4 EV (also FCV)

Industry Efforts

Honda Insight Hybrid Electric Vehicle

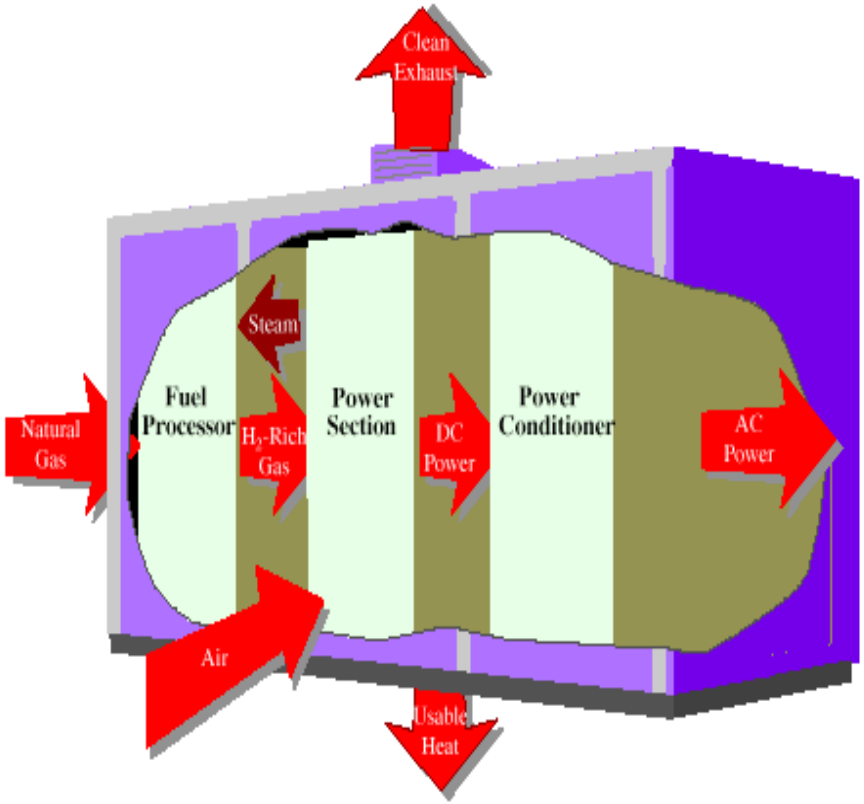
Industry Efforts

ZEVCO Alkaline Fuel Cell Taxi

Industry Efforts

Hydrogen Gas Station in Hamburg, Germany

Fuel Cell Power Plant



Integrated Electricity and Heat Production

Modular, Distributed Generation

Fuel Flexible

Zero-emission, Depending on Fuel

Fuel Cell Power Plant

Grid-connected or Grid-independent

Thermal Energy Temperature 140 degree F hot water (60 degree C)

Electrical Efficiency 40 %
Total Efficiency (Electric + Heat) 80%

Natural Gas Consumption 1,900 cubic feet per hour

Pollutant Emissions less than 6 ppmv (total)

Sustainable Transportation

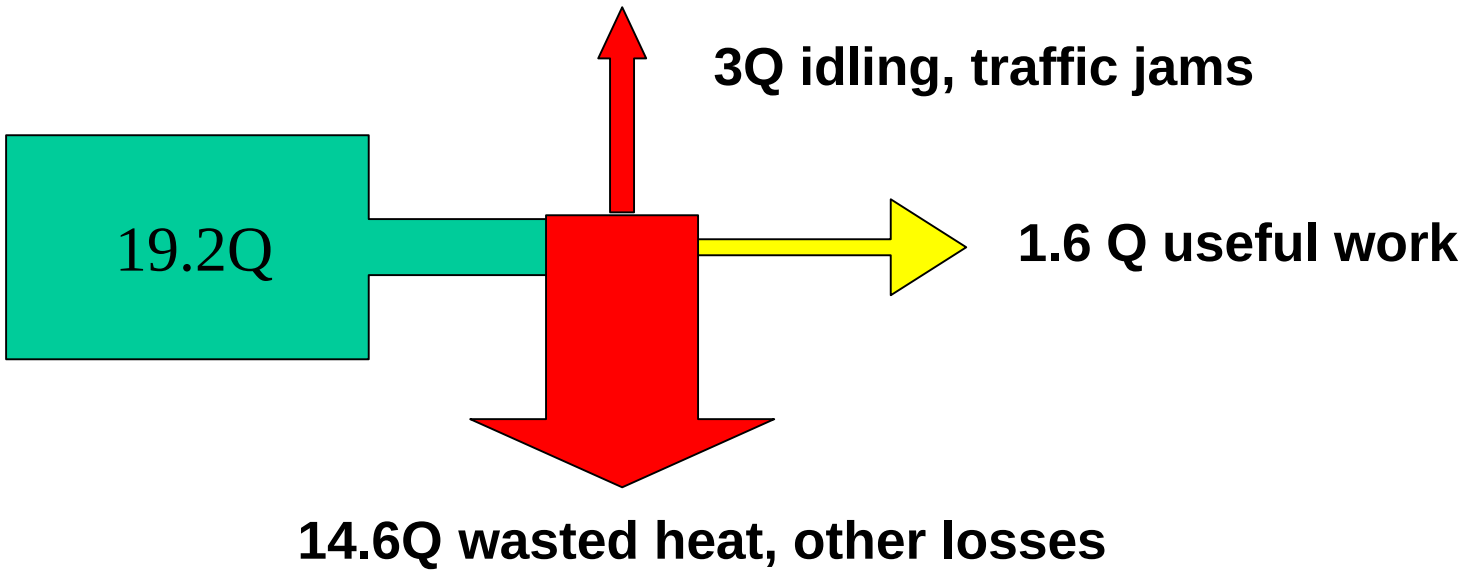
- Strategic Potential of Fuel Cells
  - Fuel Choice
  - Transportation
  - Distributed generation
  - Integration of renewable energy and fuels

Sustainable Transportation

- Strategic Implications
  - Fuel choice is critical
  - Fuel cells can integrate renewable energy, fuels, and technologies
  - Renewable Energy Power Packages
    - Transportation
      - Direct ethanol fuel cells
      - Renewable hydrogen fuel cells
      - Fuel cell hybrid electric vehicle systems

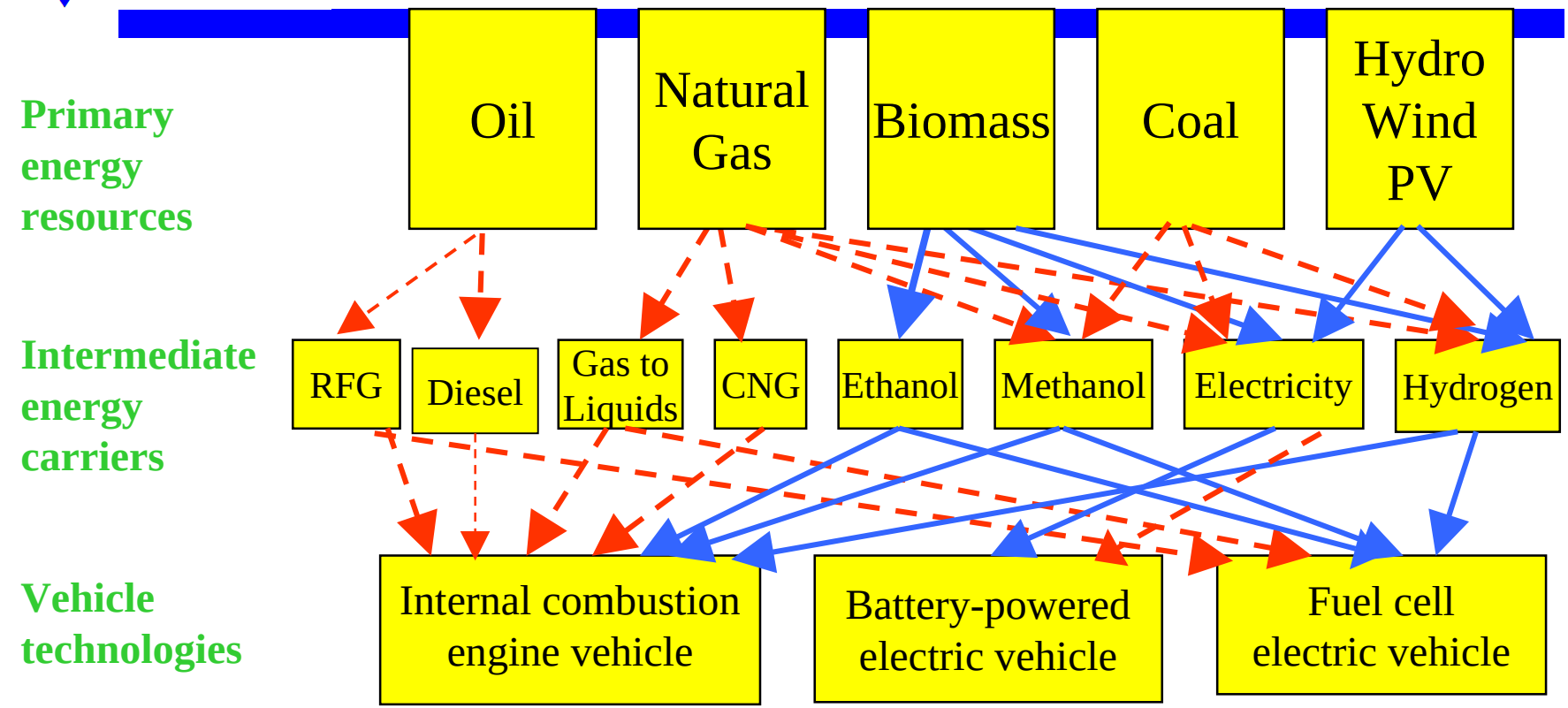
Why Fuel Choice is Important

- US Transportation Energy Flow 1992

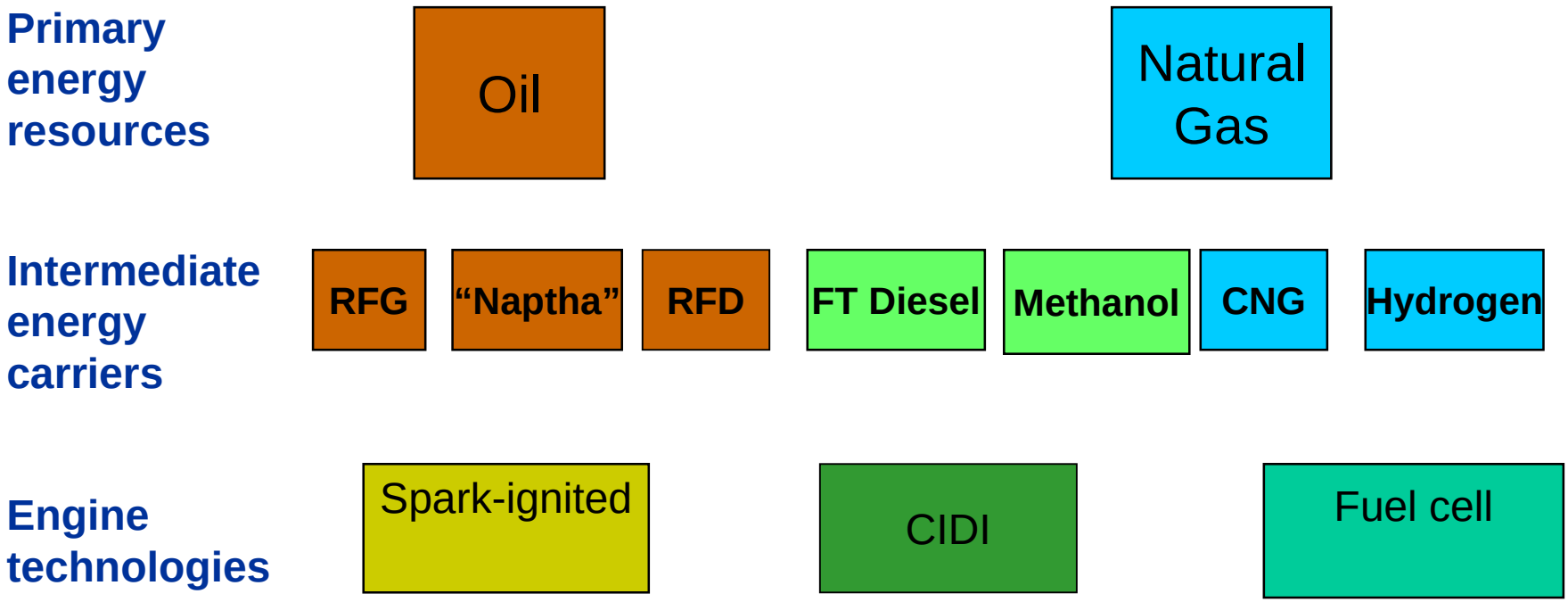


Source: Bassett, EPA

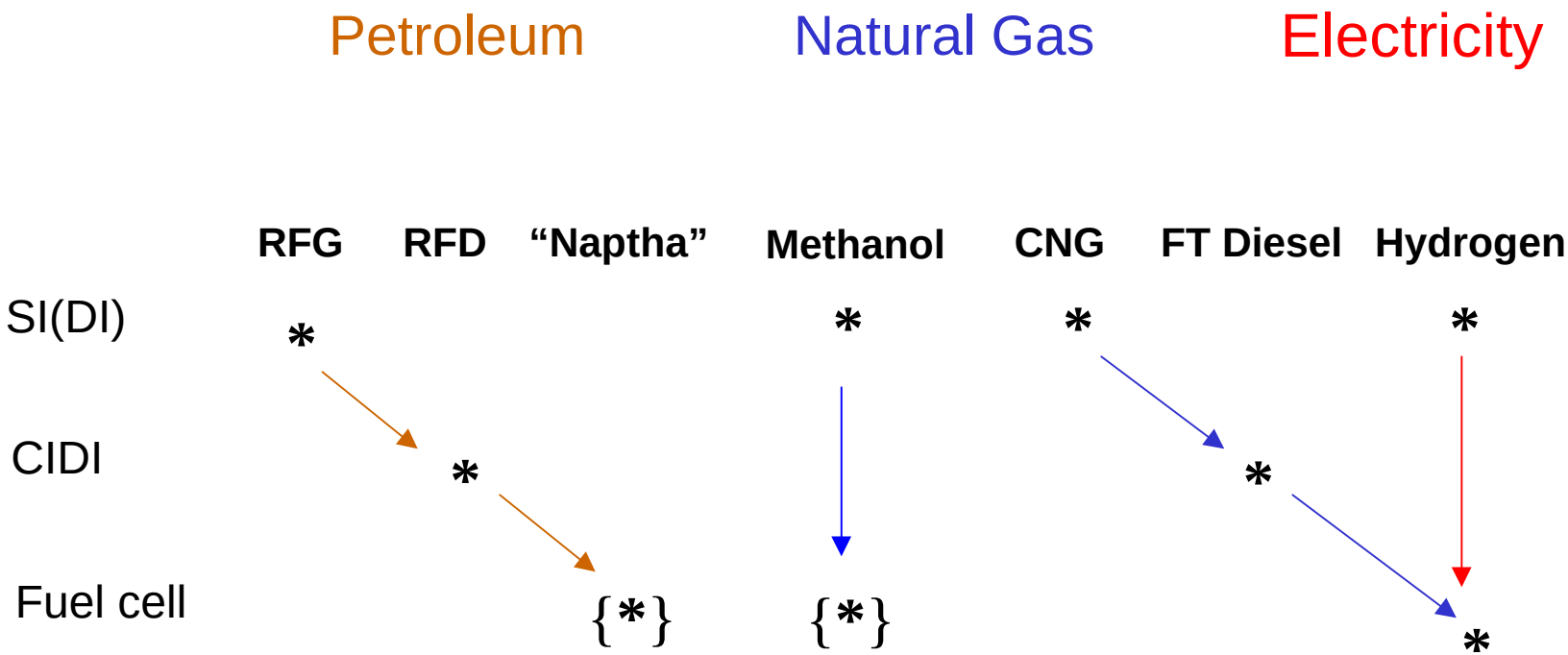
Alternative Pathways: Renewable and Non-renewable



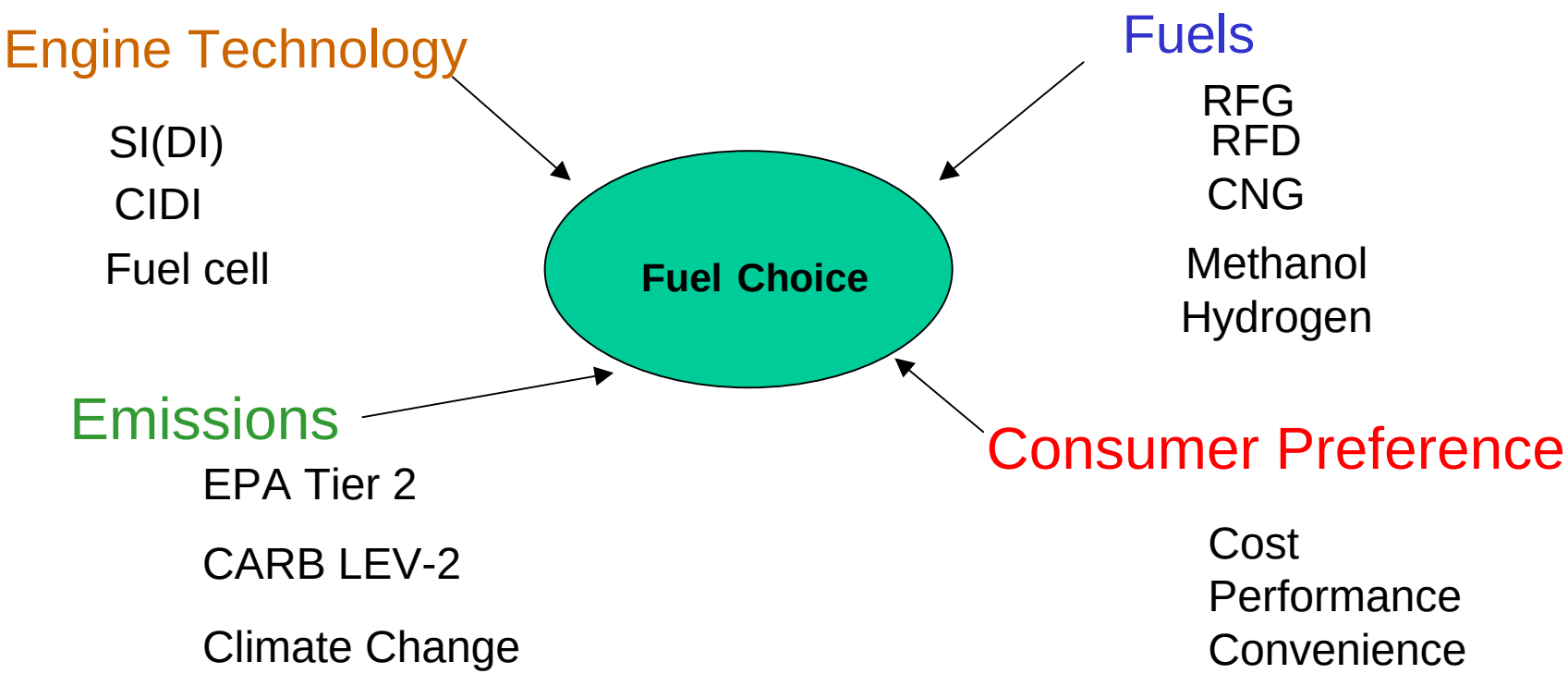
Alternative Pathways: Liquid vs. Gaseous Transportation Fuels



Alternative Pathways: Liquid vs. Gaseous Light-Duty Vehicle Fuel Transitions



Fuel Choice: Convergence of Key Factors



Efficiency and Emissions

- Storing hydrogen vs. reforming liquid fuels
  - Direct storage options are limited and may be problematic
    - high-pressure gaseous or cryogenic storage
    - weight, temperature requirements for chemical storage
    - advanced materials, e.g., carbon nanotubes
  - On-board reforming options may be problematic
    - thermal integration, fuel requirements, gas purity, efficiency
    - start-up and transient response, catalysts, emissions
    - controls and packaging
    - cost

Key Questions

- feedstocks (fuel sources) anticipated for fuel/reformer technology
- total costs for fuel system options and anticipated life cycle emissions for each option
- regulatory requirements needed for commercial development and implementation, e.g., codes and standards, DOT rating, other permits
- vehicle-system process integration required

Fuel Choice: Critical Issue

- Fuel Choice is a critical issue for national energy policy
  - Hydrogen is an enabling technology that links renewable energy and zero-emission technologies
  - Fossil-based fuels and engine technologies have a long-history of development and are continually improving
- Fuel Choice is a multifaceted issue with many competing options available
  - Complex tradeoffs will be made among all of the key criteria

Sustainable Energy Production

- Strategic Implications of Fuel Cells
  - Renewable Energy Power Packages
    - Distributed Generation
      - biomass-fired fuel cells
      - wind, solar electrolyzer-fuel cells
      - integrated building energy systems

Conclusion

- Fuel cells can lead the way to sustainable transportation and use of energy resources
  - link zero emission energy conversion and renewable fuels
    - renewable hydrogen production
    - bioethanol production